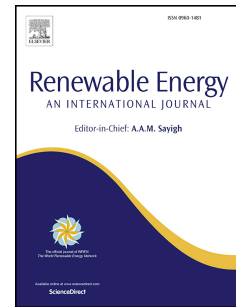


Accepted Manuscript

Comparative analysis of hybrid renewable energy systems for off-grid applications in Southern Cameroons

Erasmus Muh, Fouzi Tabet



PII: S0960-1481(18)31424-1

DOI: <https://doi.org/10.1016/j.renene.2018.11.105>

Reference: RENE 10868

To appear in: *Renewable Energy*

Received Date: 26 April 2018

Revised Date: 3 November 2018

Accepted Date: 29 November 2018

Please cite this article as: Muh E, Tabet F, Comparative analysis of hybrid renewable energy systems for off-grid applications in Southern Cameroons, *Renewable Energy* (2018), doi: <https://doi.org/10.1016/j.renene.2018.11.105>.

This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

Comparative Analysis of Hybrid Renewable Energy Systems for Off-grid Applications in Southern Cameroons

Erasmus Muh^{a,*}, Fouzi Tabet^b

^a Pan African University, Institute of Water and Energy Sciences (including Climate Change), BP 119 Tlemcen 13000, Algeria. E-mail: muhrace@yahoo.co.uk

^b DBFZ - Deutsches Biomasseforschungszentrum Gemeinnützige GmbH, Torgauer Straße 116, D-04347 Leipzig, Germany

Abstract

Cameroon is blessed with a vast potential of renewable energy resources: solar, biomass, hydropower, wind and geothermal energies. These resources are currently poorly valorized. The country depends mainly on hydropower for its electricity supply and traditional biomass for its energy consumption. This dependency on hydropower causes acute power shortage nationwide, especially in remote communities where grid access is limited. Rural electrification is mainly conducted through costly grid extensions, small hydro and diesel plants with enormous health and environmental effects. This study assesses the feasibilities of hybrid renewable power systems for remote applications in Southern Cameroons using the climate data of Wum. HOMER was used to perform the comparative analysis. Nine hybrid systems were considered in this study based on the following components: PV module, wind turbine, micro-hydro turbine, diesel generator, battery, charge controllers, and inverters. Two energy sources and storage battery characterized each system. The PV/diesel/small hydro/battery was found to be the most viable economic system for Southern Cameroons with a 0.443\$/kWh energy cost. The optimum system was proven to be very resilient to variations in streamflow, interest rate, fuel price, and PV cost. This outcome was found to be highly relevant to policy makers and investors in Cameroon.

Keywords: Renewables, Hybrid systems, Rural electrification, Cameroon, Energy access

1.0 Introduction

Cameroon (fig. 1) is located on the Gulf of Guinea with its larger and smaller landmass in Central and West African regions [1, 2]. It is bordered by Nigeria in the West, Chad in the North, the Central African Republic in the East and Gabon, Equatorial Guinea and Congo in the South [1, 3]. Cameroon has a population of 24,360,830 inhabitants (July 2016) and a total surface area of 475,440 km². More than half of this population lives (54.4%) in urban centers in 2015 [4]. Estimates in 2000 revealed that about 48% of Cameroon's population (mainly in rural areas) live below poverty. Rural poverty in Cameroon is attributed to inadequate access to modern energy services, high illiteracy rates, poor telecommunication infrastructures, low employment rate and poor access to information [5]. The country has a coastline of 402 km with a climate that varies within the terrain from semi-arid and hot in the north to tropical in the coast [4].



Fig. 1. Geographic map of Cameroon [6].

Energy is a key driver for development. Electricity plays a vital role in development irrespective of the source [7] and sustainable development requires sustainable power generation.

Access to electricity and increase the availability of electrical energy contributes to improving health, social development and fosters economic growth. The prosperity and wealth of developed countries arise from their unrestricted access to energy, whereas the developing nations are still struggling to meet up with their energy demand [8]. Lack of adequate energy in an economy is a viable source of economic and social poverty since access to modern energy services plays a fundamental role in poverty reduction and socioeconomic growth [9]. This indicates that improving energy access to remote communities is a viable and effective tool for sustainable development.

Recent studies [10] show that about 17% of the world population (1.2 billion people) mostly in Asia-Pacific and sub-Saharan Africa still have no access to electricity. This number (1.2 billion) has reduced from 1.5 billion, mainly due to the use of distributed renewable power generations to provide energy to these populations. Most of these people lived in remote and isolated areas of developing countries with difficult access to the regional or national grid. In sub-Saharan Africa as of 2008, 587 million people (70% of the population) lacked access to electricity and by 2030, it is estimated that 698 million people will still lack electricity access [11]. Ten million people, representing between 25-49% of the Cameroonian population in 2012 has no access to electricity [12]. These countries, with the exception of South Africa, have low public and households grid or off-grid energy access rates, unreliable power supply, high energy cost and inadequate production capacities to meet the rapidly growing energy demand. Two-thirds of the sub-Saharan population live in remote, isolated and sparsely populated areas without access to the national grid. Grid connections are often highly expensive in most cases and off-grid power generations are certainly the most viable option to ensure a reliable and affordable energy access to these localities [11]. In Cameroon, electrification is mainly performed through grid extensions supported by small hydro schemes and isolated diesel plants in rural settings. Electricity generation is dominated by hydropower (55.1% in 2016 [13], as compared to 73.2% in 2014 [14]), with a total production of 8,367 GWh [13], followed by thermal sources (oil and gas), biofuels with very negligible contribution and other renewable sources like solar and wind. Currently, Cameroon has an installed generation capacity of 1,475 MW [15], mainly from hydro and the rest from thermal plants. The country has an energy access of 55%; 88% urban and 17% rural [10, 15].

Nearly 3 billion people worldwide rely on traditional biomass for cooking, heating, and lighting, and this has resulted in about 3.1 million premature deaths annually, especially in developing countries as a result of indoor air pollution from incomplete biomass combustion [16]. In sub-Saharan Africa and Asia-Pacific, 2.7 billion people (38% of the global population) lack clean cooking facilities [10]. In Cameroon, 64.1% of the total primary energy consumption is derived from biofuels and waste (mainly traditional biomass) [12] and accounts for 68.7% of the country's primary energy supply [13]. The majority of the traditional biomass consumers is rural dwellers. In order to address the rapid growth in global energy demand and electricity access deficits, especially in the rural communities of developing countries, it is imperative that energy is produced and used in a sustainable way so as to achieve sustainable energy for all [16].

Therefore, there is a high need for alternative and clean energy resource development to meet these needs. This will improve energy security, increase energy access, particularly to remote communities, reduce dependence on grid electricity, increase productivity and contribute to energy diversification and security [16]. Southern Cameroons historically represent the two English speaking regions of Cameroon (North West and South West Regions). There are no power plants in these regions, although there is great potential for power development. Traditional grid power access is limited and often impossible in most rural settings. Power outages are also very frequent and there is a high dependency on paraffin and firewood.

Even though grid electrification is the first-choice measure of electricity supply in most developing countries, it is often uneconomical and expensive especially in low demand and isolated areas. Therefore, there is a need for alternative energy sources to enhance global energy access, especially in developing countries. Renewable energies have received a lot of attention in the past decades in power generations, mainly due to the fear of fossil energy depletion, oil price variations, and the fast-growing awareness on the associated dangers of climate change [17]. Single technology based renewable energy systems is a viable option to improve energy access of remote and isolated areas and their application varies with topology, resource availability and weather conditions. Solar Photovoltaic (PV) is suitable in plain areas, and rooftop PV in buildings of urban areas. Biomass gasifier/biogas systems are appropriate in remote forest areas and micro-hydro system in remote hilly areas. However, due to site specificity and intermittent nature of some renewable sources (solar and wind), standalone systems are often not reliable in power supply and costly due to the integration of storage systems to manage supply variations [18]. In addition, the independent use of standalone systems requires considerable oversizing of components to ensure system reliability and this makes the systems very costly [19]. A viable solution to this is to combine different renewable energy sources to form a hybrid system where a deficiency in the output of one system will be complemented by the other. These systems cost less, provide cheap power to remote villages, have fewer gestation periods, are almost pollution free, are user and socially friendly and are important sources of energy for school, hospitals and clinics, shops and public places in remote areas [20]. Also, they enhance energy efficiency, energy conservation, reduce and/or avoid storage, improve power quality and supply reliability. It is for these reasons that hybrid renewable energy power systems are chosen for applications in Southern Cameroons. This study assesses the feasibility and reliability of renewable energy-based hybrid systems as off-grid solutions to increase energy access in isolated communities in Southern Cameroons, as well as in maintaining energy security through resource diversification in these regions.

This paper is structured into five sections. Section one introduces the topic and also presents a deep scientific review of the literature on renewables and hybrid systems applications in Cameroon as well as the energy landscape of the country. In section two, a step-by-step methodology for obtaining the various energy resource and climate data required for the study is highlighted. Section three indicates and presents the detail characteristics and specifications of the various components of the hybrid systems under investigation, as well as the assumptions

made, systems constraints and criteria for comparing the systems. The results of this study, and hence the discussions are presented in section four. Finally, section five illustrates the conclusions, recommendations and the extent of applicability of this study, especially with respect to energy security and climate change mitigation in the country, region, and continent as a whole.

1.1 Cameroon brief energy overview

Cameroon is blessed with an abundant reserve of natural and energy resources such as timber, uranium, iron, cobalt, nickel, platinum, oil, biomass, natural gas, solar, coal, hydropower, wind, and geothermal energy. However, these resources are poorly exploited and the country's economy is powered mainly by hydropower and fossil resources [14]. Petroleum, Coal, and hydropower are the major commercial energy sources in the country with an estimate of about 90% of rural populations relying on various forms of traditional biomass for their basic energy needs (lighting, cooking and heating). Cameroon's oil reserves (2015) is estimated at 200 million barrels. The natural gas potential is of over 550 billion m³ with estimated proven reserves of 157 billion m³ [14]. According to the International Energy Agency (IEA), in 2016, the energy balance indicators of Cameroon (population of 23.34 million, GDP of 32 (billion 2010 USD)) [21] were as follows: the country's energy production was 11,953 ktoe, total primary energy supply (TPES) of 9,272 ktoe, electricity production 8.37 TWh and an overall Carbon dioxide (CO₂) emissions 6.01 Mt. The majority of the energy production (53.3%) (fig. 2a) and TPES (68.73%) (fig. 2b) and energy consumption (73.3%) (fig. 2c) come from biofuels and waste (biomass). Sectorially, the residential sector (fig. 2d) consumes the greatest share of the energy with 63.0%, followed by the transport sector with 14.5%. Electricity generation in the country (fig. 2e) is dominated by hydropower (55.11%) and most of the electricity generated (55.7%) is consumed in the industry (fig. 2f) [13]. From this brief statistic, it is evidently clear that the country depends solely on biomass energy in the form of traditional biomass for its basic energy needs, petroleum products for transportation and hydropower for electricity generations. Very little efforts have so far been made for the exploitations of the vast renewable energy potential in the country.

The distribution of electricity in Cameroon is uneven despite the rich energy resource potentials in the country, particularly hydropower. Presently, there are no grid interconnections with neighboring countries and the local grids only serve 20% of the population, mainly urban dwellers [14]. Power distribution in the country is operated by three discontinuous grids which inhibit power transfer between the grids. These grids are the southern interconnected grid (SIG), the northern interconnected grid (NIG) and the eastern isolated grid [22, 23, 24]. Each grid is solely responsible for generating power to meet the needs of its customers. The NIG, with a power source from Lagdo and 14 MW thermal plant supplies the northern regions of the country; the EIG powered by 86 small thermal units supplies the eastern regions while the SIG powered the southern regions [5]. Electricity transport in the country is operated through three distinct transmission lines: 225 kV, 90 kV, and 15 kV as well as medium and low voltage lines. There are considerable tension drops and energy losses arising from very long distances between energy production and distribution centers [23, 24].

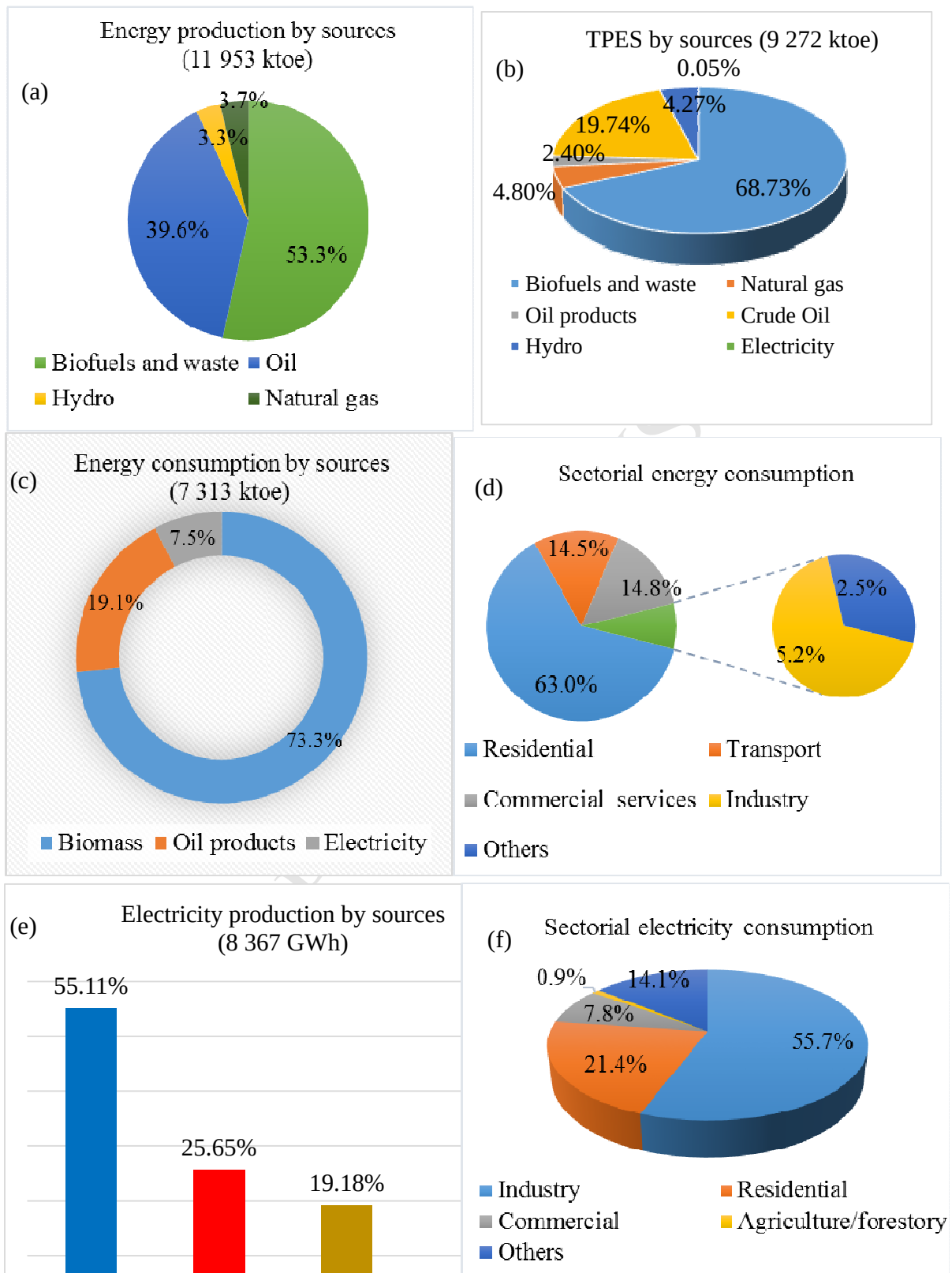


Fig. 2. Cameroon energy and electricity production and consumption in 2016 [13].

1.2 State of art of renewable energy studies in Cameroon.

Research in renewable and hybrid energy systems is limited in Cameroon. However, a number of quality research papers have been documented in the literature, cutting across resource potential assessments, policies and regulations, technologies, socio-economic and power generation and transmissions. Abanda (2012), assessed the renewable energy resources of Cameroon and concluded that there is limited and scattered research work on their potentials. Benefits and market potentials are still not properly known [25]. Similarly, in [26] the renewable energy readiness for Cameroon and Nigeria was investigated. Although both countries are developing renewable to power their local economies, they are still to incorporate renewable into their national grid on a larger scale. The study performed in [27] investigated the feasibilities of residential standalone PV systems in Cameroon for the electrification of T4, T5 and T6 residential buildings in Yaoundé. Another analysis conducted in [2], evaluated the energy generation potentials of PV systems in Cameroon using satellite-derived solar datasets at 33 sites in the country and a payback period of 5.6 years, levelized cost of energy (LCOE) of 6.79 €/kWh were achieved in sites with annual power output of 1764 kWh/kWp. Nfah and Ngundam [28] modeled Wind/diesel/battery systems for electrification of typical rural households and schools in remote areas of the Far North region of Cameroon using the wind resource data of Maroua Salack. The overall result obtained in this study indicated a high possibility of increasing electricity access rate in the Far North of Cameroon using Wind/diesel/battery systems without the consideration of grid extensions, building new thermal power plants or implementing independent diesel plants to supply power to the remote communities [28]. In another modeling study [29], the performance of hybrid Solar/diesel/battery system for the same locality of Cameroon using Hay's anisotropic model to calculate the hourly solar radiation received on a south-facing tilt module from the hourly global horizontal radiation of Garoua was investigated. Furthermore, the feasibilities of pico-hydro and PV hybrid systems with the incorporation of biogas generator for remote villages in Cameroon using 73 kWh/day and 8.3 kWp load was evaluated in [22]. It was observed that a pico-hydro/biogas/battery system in the South of Cameroon with a minimum flow rate of 92 l/s was more economical than a PV/biogas/battery system for Northern Cameroon with a minimum insolation level of 5.55 kWh/m²/day. In another work using HOMER software [30] to simulate an off-grid generation options for remote villages in Cameroon to fulfil 110 kWh/day and 12 kWp loads based on the flow rate of Mungo river and the solar resource of Garoua, it was found that the micro-hydro hybrid is the cheapest solution for remote areas in the south of Cameroon and PV the cheapest in the north.

From the above survey, it was shown that few studies were dedicated to renewable energy potential assessment and hybrid systems applications for rural electrification in Cameroon. In addition, most of the available studies are conducted in the northern part of the country with a focus on hybrid systems based on diesel or liquified petroleum gas (LPG) gensets. The aim of the present study is to investigate the performances of a wide range of renewable hybrid systems for rural electrification in Southern Cameroons in order to select the best system based on preselected criteria. Nine hybrid systems are retained for the analysis based on the

following components: PV module, wind turbine, micro-hydro turbine, diesel generator, battery, charge controllers, and inverter. Two energy sources and storage battery characterize each system.

2.0 Electrical load and energy resource assessment

The climate data of Wum, in the North-West region of Cameroon, is used to represent the resource data for Southern Cameroons. Wum is chosen due to its remoteness and the extent of resource availability. Wum is located at latitude 6.4°N and longitude 10.1°E. Its elevation is 1,101 m above the sea level. This section introduces the following parameters which are needed for setting up the simulation: electrical load profile, diesel fuel price, solar potential, small hydro potential and wind potential. The flow rate of the Mungo river which cuts across the Littoral and South West regions of Cameroon is used as hydro resource data in this study.

2.1 Electrical load estimation

The electrical load requirement of the village is assessed through a field survey of household energy consumption, using energy appliances and typical village consumption durations. All household size and consumption durations are considered equal. Field survey demonstrated that the household size varies from three family members (medium) to seven members and an average family size of five is used in the study. In addition, a total of 500 households (2,500 persons) is considered. The load was divided into three categories: households, community, and business. For each consumer class, the load of a single user was calculated by summing up the product of each of the user's appliance wattage with the daily usage duration, and the overall village load was obtained by summing up together overall individual consumption of the various consumers' classes. This community load considers only loads that need to be met immediately (primary load) such as lighting, cooking, radio, etc. An overall load estimation of 100 kWh/day (35.17 kWh peak) was obtained. This is the mean daily load profile of all the three consumer classes for each weekday of the month and of the year. It is assumed the same through throughout the project life. Also, variations in hourly, daily, monthly and seasonal power generations and consumptions are considered negligible. Detailed of this load estimation is shown in table 1. The computed village hourly, daily load profile is presented in figure 7 (sub-section 4.1).

257

Table 1. Community load estimation

Village daily Load estimation									
Load Category	block/section	Appliances	Quantity	Watts (W)	Usage hr/d	Usage hr/d	Wh/d (AC load)	Total category Load /d	
Nursery School	Classroom (02)	Bulbs	4	9	8:00-10:00	2	72	741	
	1 Office	Bulbs	2	9	8:00-10:00	2	36		
		External bulbs	1	9	18:00-6:00	12	108		
		Electric heater	1	1000	8:00-8:30	0.5	500		
		Radio/charger	1	5	8:00-1:00	5	25		
Primary School (02)	6 Classrooms	CR Bulbs (4)	48	9	7:00-09:00	2	864	1151	
	2 Office	bulb-IN	2	9	7:00-09:00	2	36		
		bulb-EX	2	9	18:00-6:00	12	216		
		Radio/charger	1	5	7:00-14:00	7	35		
Secondary School (01)	5 Classrooms	bulbs (4)	20	9	7:00-09:00	2	360	1539	
	3 Offices	bulbs (2)	6	9	7:00-9:00	2	108		
		Office bulb-EX	3	9	18:00-07:00	13	351		
		office desktop	3	60	9:00-12:00	3	540		
		Printer	1	60	8:00-10:00	2	120		
		Photocopier	1	60	10:00-11:00	1	60		
Health Clinic	5 Wards	bulbs (8)	40	9	18:00-12:00	6	2160	8272	
	2 Offices		40	9	4:00-7:00	3	1080		
		bulbs (2)	4	9	19:00-7:00	12	432		
		bulbs-EX	5	9	18:00-6:00	12	540		
		Vaccine refrigerator	1	80	24hrs	24	1920		
		microscope (2)	2	20	9:00-11:00	2	80		
		radio/charger	2	5	11:00-17:00	6	60		
		Electric heater	1	1000	5:00-6:00	1	1000		
		1	1000	18:00-19:00	1	1000			
Community Mills		Flour mills (5)	5	1000	8:00-9:00	1	5000	15000	
			5	1000	16:00-18:00	2	10000		
Households (500)	4 rooms	bulb (1)	2000	9	20:00-21:00	1	18000	59400	
	1 living room	bulb (1)	500	9	18:00-21:00	3	13500		
	1 kitchen-EX	bulb (1)	500	9	19:00-21:00	2	9000		
	External lighting	bulb-EX	50	9	18:00-21:00	3	1350		
		Radio/charger	150	5	6:00-9:00	3	2250		
			150	5	15:00-21:00	6	4500		
Small businesses (50)	50	TV	90	60	19:00-21:00	2	10800	3300	
		bulb	50	9	18:00-21:00	3	1350		
		Bulb-EX	50	9	18:00-21:00	3	1350		
		Radio/charger	20	5	7:00-9:00	2	200		
				20	5	17:00-21:00	4	400	3300
NB: EX = External, IN = Internal				Safety load		10%*89406		8940.3 W	
Total load						98343.3		100 kWh/d	

258

2.2 Solar radiation data

The mean monthly global horizontal Solar radiation data (22 years average) and clearness index (fig. 3) of Wum were obtained from the NASA Surface Meteorology and Solar Energy website [31], using the exact location of the site: latitude and longitude. As seen from fig. 3, monthly and seasonal variations in global solar radiation and hence the energy output of solar energy systems in Wum occur. The site shows significant radiations all year round with a mean annual global solar radiation of 5.24 kWh/m²/day. The peak radiation is observed in February (peak dry season) and the least in August (peak rainy season). The clearness index varies between 0.67 in January and 0.41 in August, with an annual average of 0.52. This shows that a great amount of solar radiation reaches the surface at Wum all year round. Based on the mean value of the clearness index in Wum, the weather condition at this site is described as being partly overcast ($0.4 \leq K_T \leq 0.6$). To investigate the effect of changes in solar radiation on the energy output of solar energy systems in Wum, a range of values of mean annual solar radiations was used for sensitivity analysis.

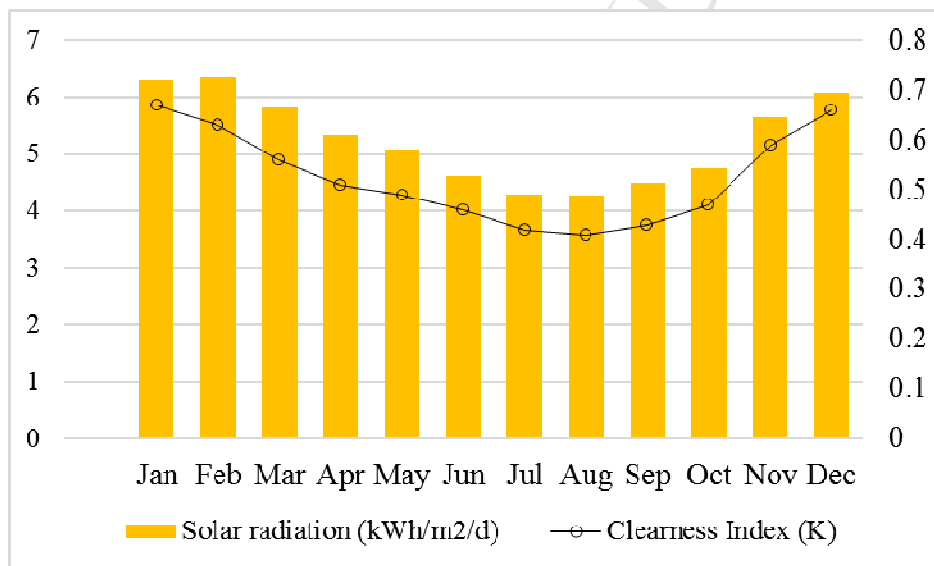


Fig. 3. Mean monthly global horizontal solar radiation of Wum [31].

2.3 Wind resource data

The monthly wind speed of Wum (10 years average) was derived from the NASA Surface Meteorology and Solar Energy website [31]. This wind speed was measured at 10 m above the ground level from 1983 to 1993. The monthly wind speed of Wum (fig. 4) and wind power output, unlike solar energy, varies from one month to the other. However, the wind speed at Wum is relatively low with a mean annual, monthly wind speed of 2.29 m/s. As a result of this low wind speed, wind turbines with low cut-in speed and power efficiency at a speed of 2.5 m/s will be used. To investigate the effects of wind speed changes on the performance of the wind energy system, a sensitivity analysis was performed based on a range of values of wind speed.

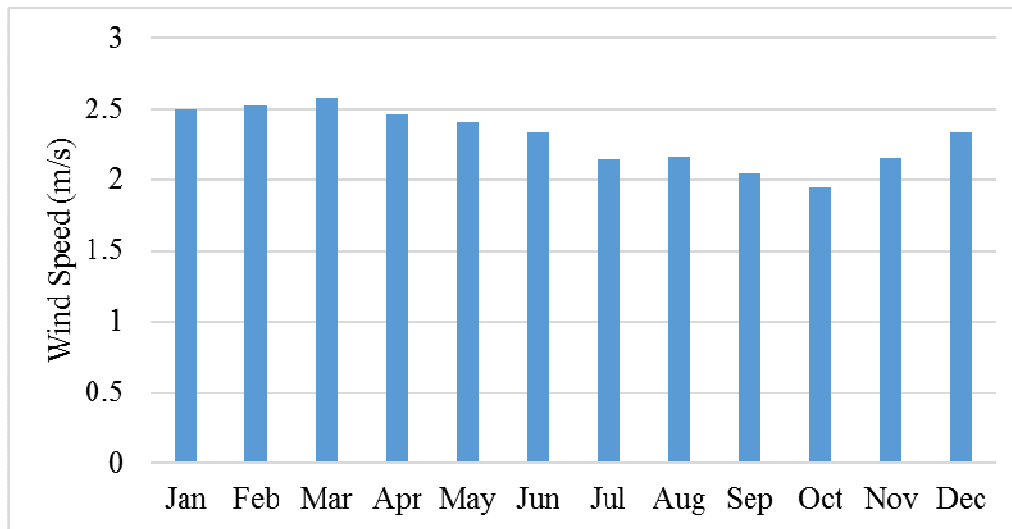


Fig. 4. Mean monthly wind speed at Wum [31].

2.4 Small hydro

The flow rate of the Mungo river [32] is used. This river cuts across the South West and the Littoral regions of Cameroon. The potential of small hydro schemes up to 1 MW in Cameroon is estimated at 1.115 TWh [3] and are spread across the country. Table 2 shows the flow rate of the Mungo river.

Table 2. Mean monthly flow rate of river Mungo [32].

The monthly mean flow rate of Mungo river (m ³ /s)													
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Flow rate	46	42	55	88	114	170	263	321	343	276	162	75	163

2.5 Diesel fuel

The diesel fuel price in Cameroon in April 2017 according to the global market price was \$0.95/l (575.00 CFA per liter) [33]. However, due to taxes, regulations and minor state subsidies on petroleum products, local distributors (Total, Tradex, etc.) sell the diesel fuel litter 600 FCFA (\$0.99/l). In this study, the local diesel price of \$0.99/l is used. The effects of diesel price on the hybrid energy system optimal performance and electricity cost were investigated by varying the local diesel price from \$0.50/l to \$1.50/l, with a rate of \$0.20/l. It should be noted that in rural areas and during periods of fuel scarcity, diesel fuel price increases and prices of \$1.00/l and above can be reached. [\$1.00 = 610.00 FCFA].

3.0 Hybrid system components and specifications

Nine hybrid systems are considered in this study based on the following components: PV module, wind turbine, micro-hydro turbine, diesel generator, battery, charge controllers, and

inverter. Two energy sources and storage battery characterize each system. Table 3 describes the components of each system. A schematic representation of these systems is given in figure 5.

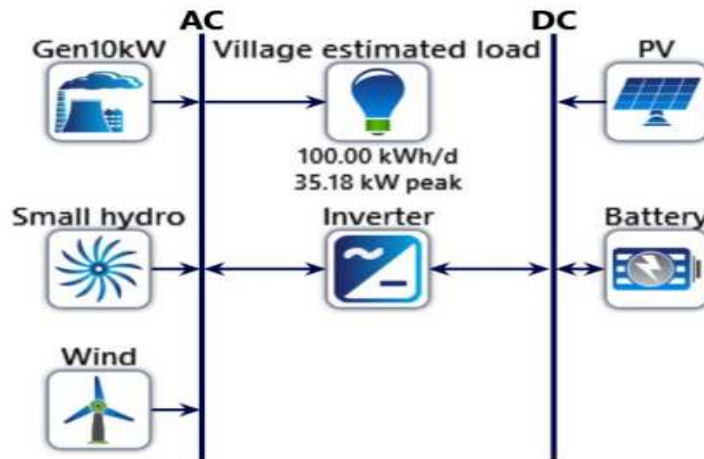


Fig. 5. Schematic representation of hybrid systems architecture.

Table 3. Proposed hybrid systems for application in Southern Cameroons.

Proposed system	Scenario
PV/wind/battery	A
PV/wind/diesel/battery	B
PV/diesel/Battery	C
PV/Wind/diesel/small hydro/battery	D
PV/wind/small hydro/battery	E
PV/small hydro/battery	F
PV/diesel/small hydro/battery	G
Wind/diesel/small hydro/battery	H
Wind/small hydro/battery	I

The design, analysis, and simulation of these systems were performed using HOMER (Hybrid Optimization Model for Electric Renewable) software, the most widely used software in this field. This tool is useful for grid-connected and off-grid hybrid power systems for centralized and distributed applications. It also permits the evaluation of the economic and technical feasibilities of the hybrid systems. It equally accounts for the variations in energy resource availability and technology cost which allows comparison of different hybrid power system options [34]. Three different analyses, namely simulation, optimization, and sensitivity are performed by HOMER software [35]. In the simulation, HOMER models system performance, hourly to provide their technical feasibility that satisfies the load requirement and other constraints applied to it. HOMER optimization searches for the lowest cost system that satisfies the technical and economic constraints, by simulating multiple configurations [36]. With sensitivity analysis, HOMER performs several optimizations using a range of input data in order

to investigate the effects of input changes on the system performances [9, 35, 37]. After these processes, HOMER displays the systems in ascending order of their net present value, with the most feasible system at the top [38].

3.1 Solar Photovoltaic (PV) module

The 250 W polycrystalline Canadian Solar PV modules with 60 (6x10) polycrystalline cells and module number CS6P-250P is used in this study. The modules are expected to be mounted on a fixed axis oriented at an angle above the ground equivalent to the latitude of the site and facing south with an azimuth angle of zero and no tracking system for cost constraints. Based on the site resource potential, the PV system will be the major contributor of the hybrid systems expected output power. The detailed specification of this module is shown in table 4 [39].

Table 4. Technical specifications of the Canadian Solar 250W module under normal operating cell temperature [39].

Parameter	Specification
Nominal Maximum Power (P_{max})	250W
Optimum Operating Voltage (V_{mp})	30.1V
Optimum Operating Current (I_{mp})	8.30A
Open Circuit Voltage (V_{oc})	37.2V
Short Circuit Current (I_{sc})	8.87A
Module efficiency	15.54%
Operating Temperature	-40 °C~+85 °C
<i>Temperature Characteristics:</i>	
P_{max}	-0.43%/°C
V_{oc}	-0.34%/°C
I_{sc}	-0.065%/°C
Nominal Operating Cell Temperature	45±2°C
Dimension (mm)	1638x982x40

The cost of a solar PV module is dependent on the size of the panel, technology (mono or polycrystalline, thin film), the brand manufacturer, the retailer and country of purchase. The lifetime of the PV module and array is assumed to be 25 years. The cost of this module in the Cameroonian market (Maguysama Technologies, Douala-Cameroon) at study time (June 2017) is 168,000.00 FCFA (\$276.00), equivalent to \$1.104/W. The total module cost is \$296.00 (\$1.18/W), with a \$20.00 installation cost per module. Replacement cost is taken as zero as the project life equals module lifespan. The PV derating factor to compensate for the reduction in efficiency of PV modules arising from temperature increases, dust accumulation, and wiring energy losses is taken as 0.8 (PV derating factor typically ranges from 0.7-0.8 for high temperatures [35]. The ground reflectance (fraction of incident solar radiation on the ground that

is reflected back to space) ranges from 20 to 70% [35] depending on the ground nature of the study site. In the study, the ground reflectance is assumed minimum (20%).

3.2 Wind turbine

The wind potential of Cameroon is relatively low. At 10 m, nationwide wind speed ranges from around 1.42 to 4.4 m/s [31], lower than the cut-in speed of most wind turbines, except for a few areas in the Far North region of Cameroon where wind speed exceeds 3.5 m/s [25]. Thus, low cut-in speed wind turbines with maximum power efficiency within the range 2.5 - 3.5m/s is ideal for this study. The Chinese Angel-500 (0.5 kW) model low wind speed turbine with detailed technical specifications in table 5 is chosen [40]. The capital cost is \$308.00, installation cost and operating costs are each 10% of the capital cost (\$30.80). This turbine has a lifespan of 20 years, but it will be replaced after 13 years for security and performance reasons and the hub of the turbine is taken as 10 m above ground level.

Table 5. Technical specification of Angel-500 low cut-in speed wind turbine [40].

Property	Specification
Brand name/model no.	OUYAD/Angel-500
Rated power (W)	500
Rated voltage (V)	24/12
Cut-in speed (m/s)	1.5 – 2.0
Rated wind speed	10.0
Number of blades	3
Rotor diameter (m)	1.44
Security wind speed (m/s)	35.0

3.3 Diesel genset

The diesel generator system is used as a backup system, mostly in periods of low power output in order to ensure system reliability and effectiveness in meeting full load demand. Here, it is assumed to indirectly play the role of the battery as a storage system and is usually sized to meet peak load demand [9, 35]. It is mainly used in times of energy generation deficiency [37]. The Kohler 10 kW/12.5 kVA generators [41] is chosen for meeting the peak load of 35.18 kWh and excess power will be used for spinning and/or as an operational reserve to be stored in batteries for later use, in expectation of changes in system's electrical load. The efficiency and fuel consumption patterns of this generator are shown in figure 6(a) and (b). From figure 6 (a), the values of a (intercept) and b (slope) are given as 0.03 L/hr/kW and 0.0352 L/hr/kW, respectively. Table 6 summaries the technical specification of this generator [41]. The price of a 10 kW/12.5 kVA diesel generator from local distributors in Cameroon is approximately 2.5 million FCFA (\$4,098.00), equivalent to \$409.80/kW. The minimum installation cost, assumed 10% of the initial capital cost, is \$409.80. This gives a total capital cost of \$4,508.00. The operating and maintenance cost of this generator model is taken as \$0.02/hr with a lifetime of 25,000 hours.

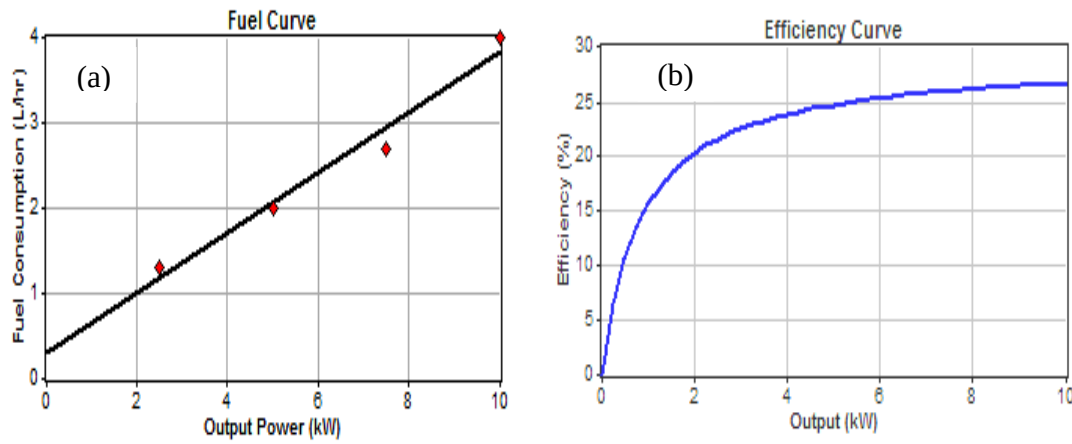


Fig. 6. Fuel consumption curve (a) and efficiency (b) of Kohler 10 kW diesel generator [41].

Table 6. Technical specification of Kohler 10 kW diesel generator.

Properties	Specifications
Standby max. Power	10 kW/12.5 kVA
Fuel consumption at 100%	4.0 l/hr, 1.1 g/h
Efficiency (Alternator)	0.82
Power factor	0.8
Frequency	60 Hz
Voltage	120/240 V
Phase	3

3.4 Small hydro turbine

An 18 kW cross-flow turbine with a head of 13 m and a design flow rate of 200 l/s [32] was selected. The effects of streamflow variations in the systems cost of energy will be evaluated using a range of stream flows from 150 to 250 l/s. The capital cost of this turbine (18 kW, 70% turbine-generator efficiency), replacement cost, operation, and maintenance cost and fixed system cost are \$10,000, \$5,000, \$500/yr and \$8,800.

3.5 Battery

Generally, the battery is used to store excess power from renewable energy systems. In this study, the 12 V True Front Access C&D Technology battery TEL12–200TFA model Valve Regulated Lead Acid battery (VRLA) of 196 Ah nominal capacity and 90% efficiency is selected [42] is selected. The capital, replacement and yearly maintenance cost of this battery in the Cameroonian market (Maguysama Technologies) are 196,000.00 FCFA (\$321.00), \$321.00 and \$10.0 respectively. The battery will be required to meet a peak load of 35.18 kWh at 60% depth of discharge when fully charged. It is assumed that changes in temperature will have no effect on

the battery performance. Table 7 summarizes the detailed technical specifications of this battery [42].

Table 7. Technical specification of TEL12-200TFA battery [42].

Properties	Specification
Nominal capacity at 10hr rate	196Ah,
Nominal voltage	12VDC
Efficiency	90%
lifespan	12
weight	60.2 kg
Dimensions	(559x125x310) mm

3.6 Inverter

As hybrid energy systems consist of both AC and DC systems, an inverter is needed to convert the electrical current from DC to AC or AC to DC, compatible with the load required energy form. In Africa, most energy appliances operate with AC. As such, DC current from systems such as PV needs to be converted into AC before it can be used to run various appliances. In hybrid systems, inverters maintain the flow of a single form of current into the load system by converting all current types of the different energy generators into a single current form that is required as the output current. As a precaution, chosen inverters in any study should be capable of withstanding the maximum AC loads and the total capacity should be at least 10% higher than the nominal AC load requirement for the system [43]. For this simulation analysis, the 5 kW Power Star W7 Inverter, with technical specifications in table 8 is retained [44]. Inverters cost depends on the capacity, the size and the type (pure sine wave or modified sine wave). The capital and replacement cost of this inverter in Cameroon is 600,000.00 FCFA (\$984.00). The lifetime is assumed to be 12 years, line efficiency 95% and maintenance cost \$10.00 per inverter.

Table 8. Technical specifications of 5 kW Power Star W7 inverter [44].

Property	Specification
Rated power	5 kW
<i>DC Input</i>	
Battery Voltage	24/48V
Start Voltage (min)	10/12/20V for 24/40/48V
Max. charging current	70/35A
<i>AC Output</i>	
Voltage	230VAC
Phase/waveform	Single phase/sinewave
Frequency	50Hz $\pm$ 0.3Hz
Power factor	0.9 – 1.0
Efficiency - line/battery mode	95%/88%

3.7 Other input constraints

Economic constraints used in this study include project lifespan of 25 years, an interest rate of 12.5% and an inflation rate of 3%. The effect of interest rate on the energy output and cost was investigated by varying the interest rate from 10% to 15%. The capacity shortfall fraction (the fraction of total load plus the operational reserves that the system fails to supply) and the operational reserve (the additional reserve capacity (load) required to maintain system operation during any sudden increase/decrease in load demand) [45] are very vital to assure the reliability of the systems. In this particular study, the operating reserve will be necessary to meet the load demand arising from changes in the system peak electrical load and from changes in parameters such as water flow rate, solar radiation, wind speed, diesel fuel price fluctuations etc. This reserve is taken as 10% of the hourly load as recommended in [35]. A maximum annual capacity shortage of 2% is chosen for the system and this is expected to occur in times of insufficient power supply from both the energy generators and operational reserve. Other parameters such as minimum renewable energy penetration of 40% and operating reserve as a percentage of solar and wind output of 10% were applied.

4.0 Results and Discussion

This section presents and discusses the economic and technical performance result of all the nine proposed hybrid systems (table 3) under study. More emphasis will be on the most economic systems to show its detailed performance analysis.

4.1 Trends in village energy consumption

The village load assessment gave an estimated daily load of 100 kWh/m²/d with a peak of 35.17 kWh between 7 - 8 pm in the evening (fig. 7). At this time, almost all the villagers are back home and almost all the appliances are running. In this study, weekend loads are assumed to be the same as for working days. This assumption is based on the possibility of a redistribution of usage hours at different periods of the day on weekends where some hours will have less load and other more. The usage durations of some appliances such as TV also increase on weekends since most children will be at home and a few will have to assist their parents in the farms.

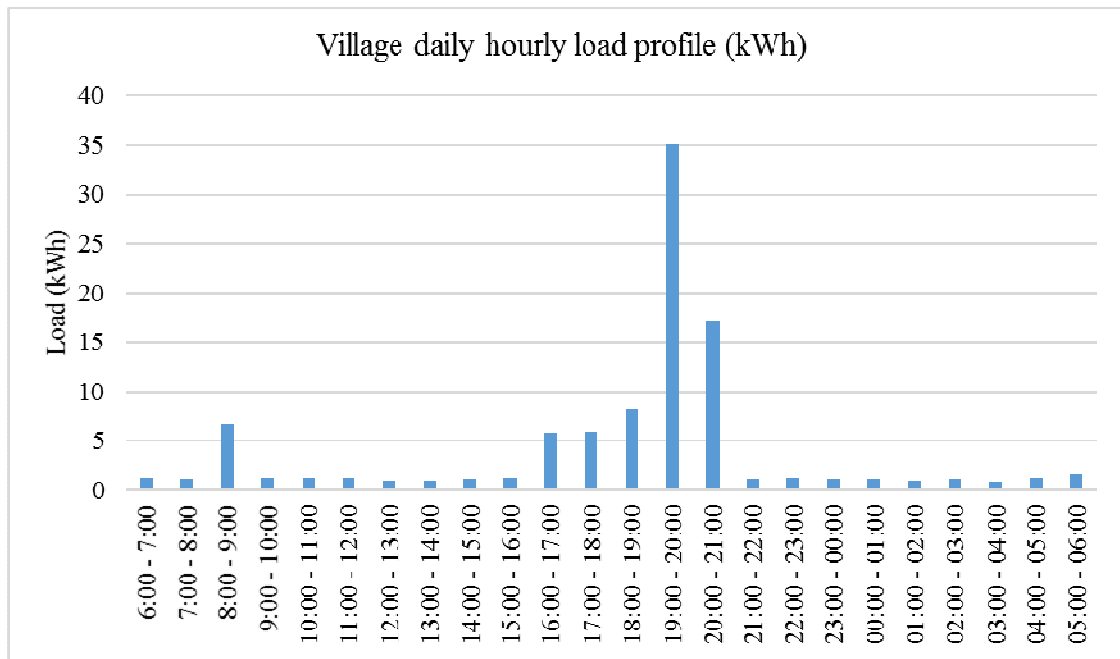


Fig. 7. Village energy consumption patterns.

The seasonal variations in the community load profile are indicated in figure 8. The fairly constant trend throughout the year is mainly due to the assumption of the same daily energy use throughout the year. This restricts profile variations.

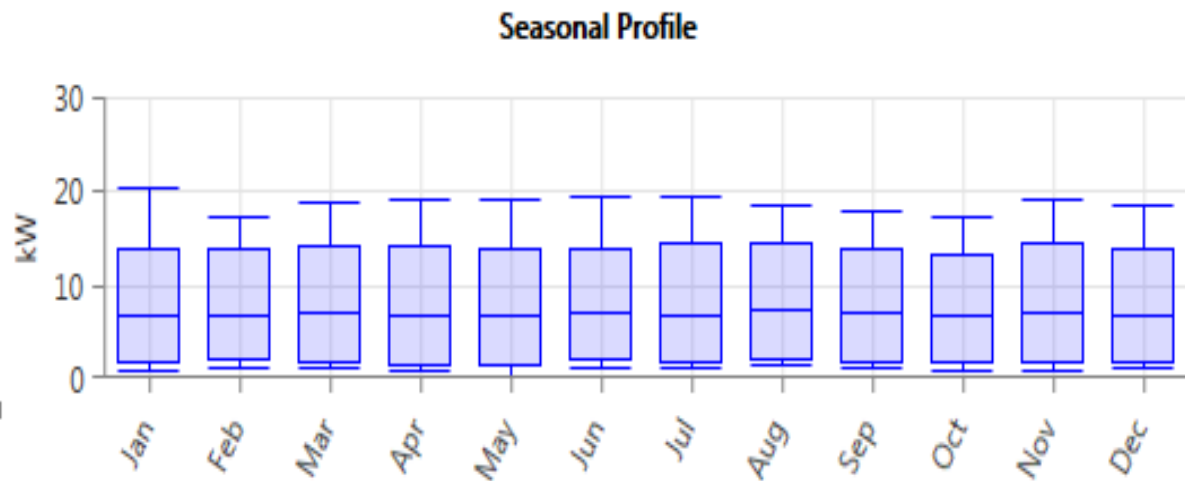


Fig. 8. Community seasonal load profile.

4.2 Analysis of overall system performance

HOMER simulation based on the above input specifications, assumptions and constraints produce a variety of energy system composition that sufficiently and reliably satisfies the load. The overall simulation results of the nine study hybrid systems in Wum are shown in table 9.

Table 9 is obtained through filtering the overall simulation results with the following constraints: PV array contribution greater than 60 kW, wind turbine units greater than 20 units, genset capacity restricted to 10 kW, the minimum size of the battery bank and lowest cost of energy. The comparison of the systems is achieved using the following criteria: minimum net present cost (NPC), cost of energy (COE), capacity shortage (low), excess production (low), fuel consumption (low), unmet load (low), CO₂ emission (low), low capital and maintenance cost and maximum renewable energy fraction; with more emphasis on the COE and NPC. In addition to these parameters, the following constraints are retained: maximum annual capacity shortage of 10%, minimum renewable fraction of 40%, current diesel price of \$0.99, a primary load of 100 kWh/m²/d, maximum annual capacity shortage of 2%, system operating reserve of 10%, and with 10% each as the percentage of solar and wind output. A maximum renewable energy penetration threshold of 40% is used. Economic constraints based on nominal discount rate of 12.5%, inflation rate of 3% and system life of 25 years are considered. These comparisons were concluded in a multicriteria decision-making approach to select the best systems at the site based on 10 design parameters. Not all the nine scenarios were found to be feasible in Wum due to resource constraints. Scenario H and I are found not to be feasible due to the relatively low wind resource potential in this area (maximum mean monthly wind speed of 2.6 m/s (fig.2)).

Table 9. Overall optimization results of the study systems.

Scenario	PV (kW)	Wind	Gen (kW)	Battery	hydro Small (kW)	Inverter (kW)	COE (\$)	NPC *1000 (\$)	Operating cost *1000	Capital cost *1000 (\$)	Ren Frac (%)	CO ₂ *1000 (kg/yr)
A	101.0	23	0	332	0	53.0	0.694	300.1	12.8	148.7	100.0	0
B	84.2	28	10	168	0	44.2	0.520	224.4	10.8	96.6	76.2	10.6
C	88.2	0	10	272	0	44.3	0.564	244.1	10.3	121.4	98.3	0.7
D	67.3	34	10	332	13.4	35.3	0.689	298.4	12.0	155.5	98.7	0.6
E	67.3	23	0	332	13.4	53.0	0.674	292.1	11.9	150.7	100.0	0.0
F	101.0	0	0	332	13.4	42.4	0.689	298.7	12.6	148.8	100.0	0.0
G	67.3	0	10	168	13.4	44.2	0.443	191.7	8.3	93.1	91.4	3.9
H	0	0	0	0	0	0	0	0	0	0	0	0
I	0	0	0	0	0	0	0	0	0	0	0	0

Taking into consideration all the design criteria, the economic performance of the various scenarios at Wum is shown in figure 9 and table 9. The scenarios performance parameters (fig. 9)

are ranked from 0 to 100, making the comparative ranking more convenient. Based on figure 9 and table 9, the economic ranking of the scenarios (in descending performances) is G, B, C, E, F, D, A; giving scenario G the overall best system that reliably satisfy the load and satisfactorily meet all the design constraints and conditions.

The CO₂ emissions from these systems (table 9) are relatively low, which confirms that these systems are environmentally friendly. The pure renewable systems (scenarios A, E, and F) have zero emission but their COE, NPC and capital costs are relatively high, making them uneconomical for local populations. The emissions from the diesel systems (scenarios B, C, D, and G) are moderate. This is mainly due to the high renewable penetrations (above 75%) of these systems and the design constraint that restricts the capacity of the diesel genset to a maximum of 10 kW. In this study, the diesel genset was not a priority but rather considered as an alternative storage system to overcome eventual irregularities of renewable resources such as wind. Scenario G still stands as the best economic system, although it has the second highest CO₂ emissions after Scenario B. this is attributed to its low COE, NPC, capital cost, operation and maintenance costs and a high renewable fraction (91%), compared to the rest of the systems.

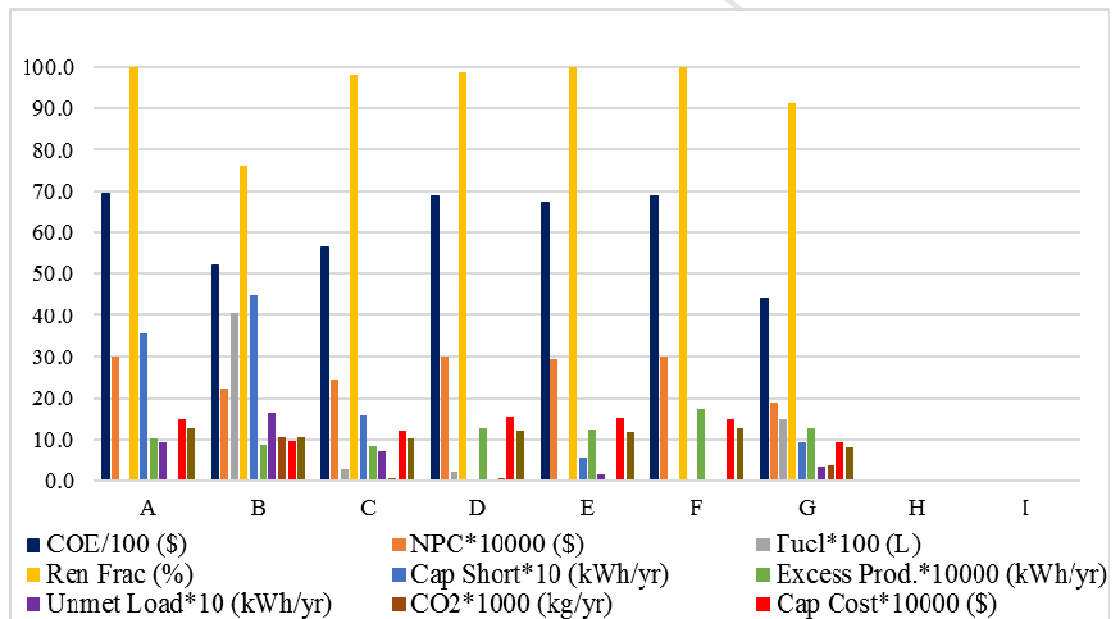


Fig. 9. Scenarios performance comparison bar chart at Wum

Considering only the COE and NPC, scenario G still remains the optimal feasible economic system at Wum. From table 9, this system has the least COE and NPC (0.443 \$/kWh and \$191,704, respectively). The renewable energy contribution of this system is very high (91.4%) and this indicates that the system can sufficiently supply the load without contribution from any non-renewable energy source. The rest of the studied systems equally showed encouraging and motivating performances on this site. Thus, if funding is not a constraint, these systems can equally be implemented on this site. Table 9 further depicts that the choice of the

optimum economic system depends on the comparison or selection criteria and the system composition. Comparing these systems based on all the above-listed criteria, system G (PV/diesel/small hydro/battery) is still the optimum system. Hence, for the rest of this study, the focus is put on system G.

4.3 Analysis of system G

System G consists of 67.3 kW of PV panel, 10 kW diesel generator, 13.4 kW of Small hydro, 168 batteries (42 strings of 4 series 12 V batteries) and 44.2 kW of the bi-directional inverter. As such, a total capacity of 45 kW inverter will be used and this will require 9 of the 5 kW Power Star W7 inverters chosen for this study. The inverters are intended to be connected in parallel strings based on the final system implementation strategy to be used.

4.3.1 Electricity production

The yearly electrical power output from this system is illustrated in figure 10, with diesel contributions in the months of January, February, March, and December (peak dry season when water levels are low). The diesel generator operation is automatic and supplies whenever there is a supply deficit from PV and small hydro. Thus, it serves as an additional storage for the facility. Solar has a fairly constant monthly and yearly generation with a slight decrease from the months of April to October (rainy season with low radiation values due to cloud covers, rainfalls and overcast conditions). Generations from the small hydro peaks in the months of July to October (peak rainy season in Cameroon), with no contributions for the months of January, February, March, and December due to low stream flows since water levels decrease with the dry period.

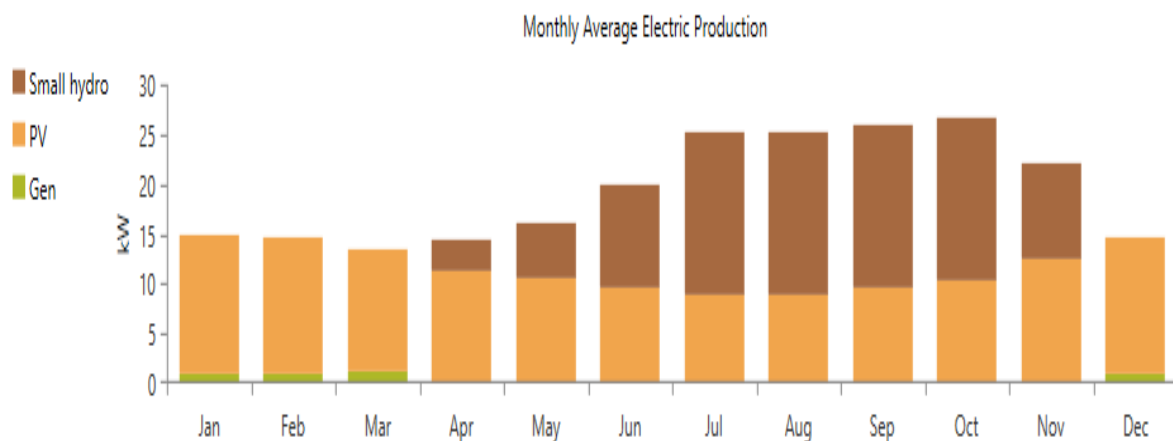
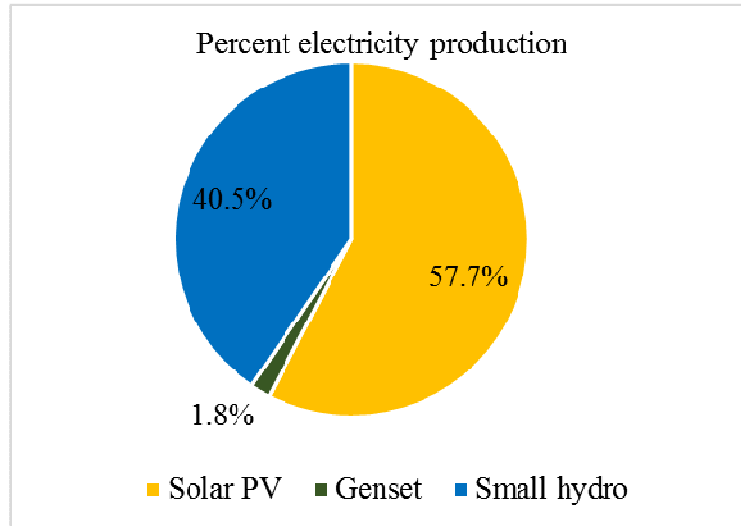


Fig. 10. Electrical power generation of scenario G.

This hybrid renewable power system produces an annual electricity of 170,095 kWh/yr (fig. 11), of which solar accounts for 57.7% (98,108 kWh/yr), small hydro 40.5% (68,851

538 kWh/yr), and only 1.84% (3,135 kWh/yr) from genset. The genset size is restricted to 10 kW in
 539 this study and it only plays the role of a complimentary storage facility.



540
 541 **Fig. 11.** The share of electricity generation from system G.

542 All the power generated by the hybrid system is consumed by the primary AC load
 543 (36,485 kWh/yr) with no deferral load. The system produces 74.7% excess power, registered
 544 0.096% of the electrical unmet load and a capacity shortage of 0.255%. The amount of excess
 545 power produced by this system is high enough to sustain future demand increases (increase in the
 546 number of households, small business expansions, increase household appliances and usage
 547 durations, as well as the connection of neighboring villages). However, harnessing these power
 548 excesses will incur an additional cost which will increase the energy cost of the system.

549 The output performance of the system PV array decreases in from March to October
 550 (rainy season). With a rated capacity of 67.9 kW, mean output of 11.2 kW, maximum output of
 551 57.8 kW and a capacity factor of 16.6%, the PV array produced a total of 98,108 kWh/yr with
 552 4,363 hours of operation; giving a LCOE of 0.0411 \$/kW and a PV penetration of 269%. The
 553 diesel component of this system is inactive for the months of May to November since solar and
 554 small hydro can adequately meet the load during these periods. The generator with an annual
 555 operation time of 1,204 hours, a capacity factor of 3.58% and 20.8 years of operational life
 556 generates a total of 3,135 kWh/yr with a mean/maximum output of 2.6/10 kW. This consumes a
 557 total of 1,475L of fuel yearly, giving an electrical efficiency of 21.6%, a fixed generation cost of
 558 0.424\$/hr and an annual power output of 3,135 kWh/yr. With a rated capacity of 10kW and a
 559 maximum output of 4.0 kW (March), the diesel genset operates under its nominal capacity
 560 throughout its operational life and this will result in enormous power losses and an overall
 561 decrease in the system efficiency. Thus, the genset needs to be resized and set to operate at full
 562 capacity or completely replace with another energy source such as biomass.

4.3.2 System G economic analysis

This system worth a total net present cost of \$191,704, giving an energy cost of \$0.443 and an operational cost of \$8,308. The NPC breakdown by components is summarized in figure 12. This cost breakdown shows that more than half of the system capital cost (\$99,946) is consumed by the storage system, followed by the solar modules (\$47,916), small hydro (\$15,935), diesel genset (\$13,962) and the inverter (\$19,943). Thus, reducing the system storage system will remarkably reduce the overall cost of the system and hence makes the system energy more affordable. Also, if the system is designed for the load to use both AC and DC appliances, the cost of inverters will be avoided and this will remarkably reduce the system and energy cost.

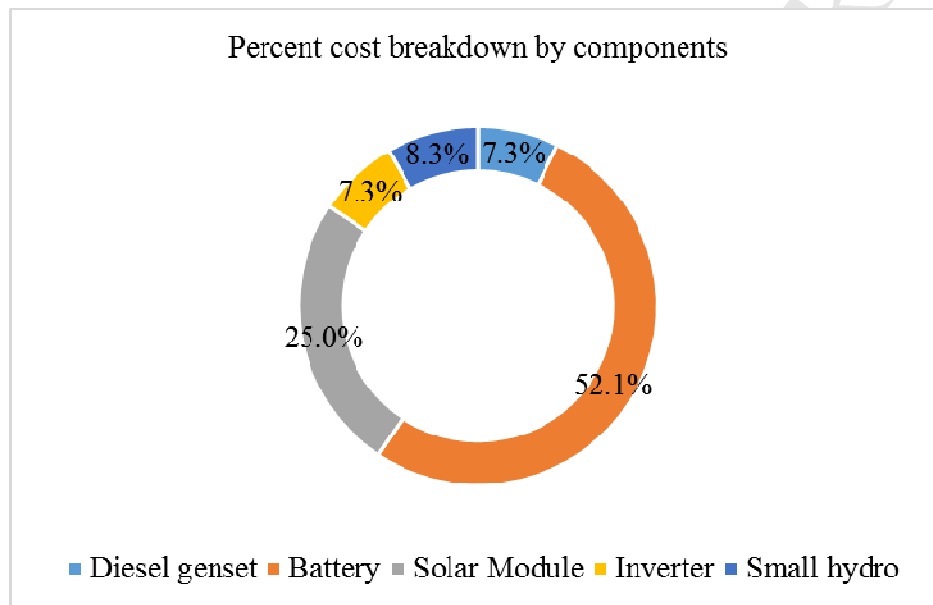


Fig. 12. System NPC breakdown by components.

From the above cost analysis of system G, reducing the storage system will remarkably reduce the system and energy cost. Thus, there is a need to explore cheaper storage options. Also, the performance of the diesel generator is not welcoming. It works below its capacity and this affects the system performance, emissions, and cost of energy. It is imperative to program it (genset) to operate at maximum capacity or replace it with other power generation sources such as biomass. The generator uses 7.3% (\$13,962) of the capital cost but produces only 1.8% (3,135 kWh/yr) of the annual system output. Thus, not economically favorable for the system.

4.4 Sensitivity analysis

Sensitivity analysis to check and evaluate the resilience of the system G to changes in input parameters was performed to give a blueprint of the system reliability. This involved an interplay of some input parameters to analyze the changes they will induce on the system performance and specifications. This enables the prediction of the effects of input uncertainties over the project life. The dependence of small hydro flow rate, interest rate, PV capital cost

multiplier and diesel fuel price on the COE and NPC were analyzed using surface plots. Figure 13 illustrates the impacts of discount rate and design flow rate on the system NPC and COE, with PV cost multiplier and diesel fuel price, kept constant at 0.2 and 0.99 \$/L respectively.

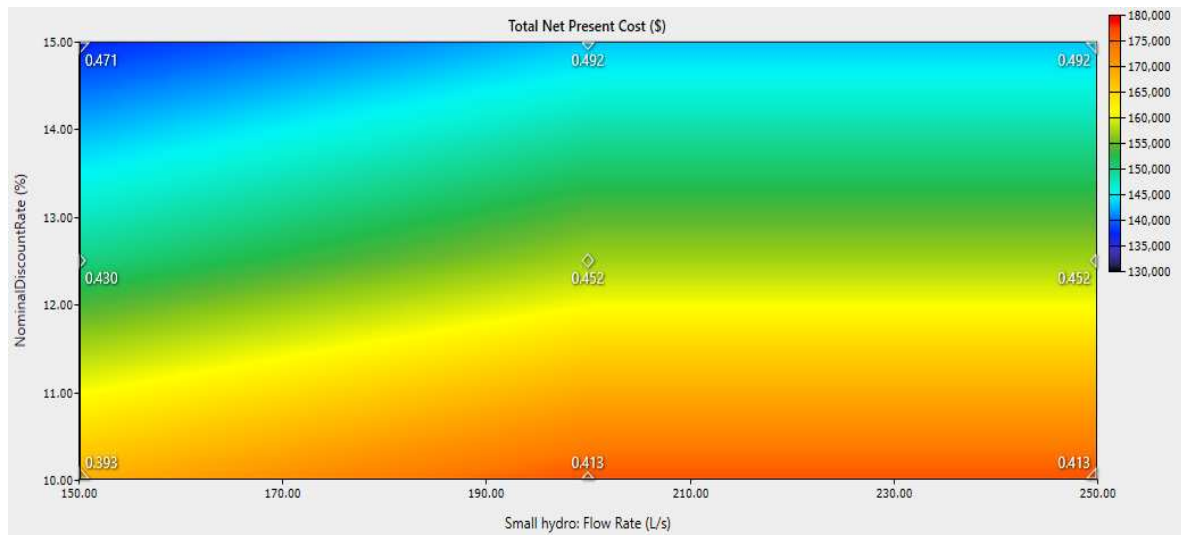


Fig. 13. Effects of flow rate and discount rate on the COE and NPC.

In figure 13, the surface represents the NPC (\$) while the COE (\$/kWh) is superimposed on the surface. As the discount rate increases from 10% to 15% (at 150 l/s design flow rate), the system's energy cost rises from \$0.393/kWh to \$0.471/kWh while the NPC drops from about \$160,000 to \$135,000. Thus, a high discount rate will make the system's energy very expensive and unaffordable by the community dwellers despite the more economic feasibility of the system with a decrease in net present cost. More specifically, when the system design discount rate drops from 12.5% to 10%, the COE drops whereas the NPC increases and when it increases from 12.5% to 15%, the cost of energy increases and the NPC falls. This shows that the discount rate effects on the COE antagonize its effects on the NPC of the system. With respect to the flow rate of the small hydro scheme and at 10% discount rate, an increase in the flow rate from 150 l/s to 250 l/s causes a slight rise in energy cost from \$0.393/kWh to \$0.413/kWh while the NPC increases from \$160,000 to \$170,000. Hence, both the COE and NPC of the system increase and fall as the flow rate rises above 200 l/s and falls below 200 l/s. This implies that low design flow favors both the economic feasibility of the system as well as energy affordability. Thus, the system design flow rate needs to be decreased to below 200 l/s to ensure the contribution of small hydro in the system energy output all year round.

The effects of diesel fuel price and PV cost multiplier on the system COE and NPV are shown in figure 14, with discount and flow rate kept constant at 12.5% and 200 l/s respectively. The surface of this plot represents the total NPC and the COE is superimposed.

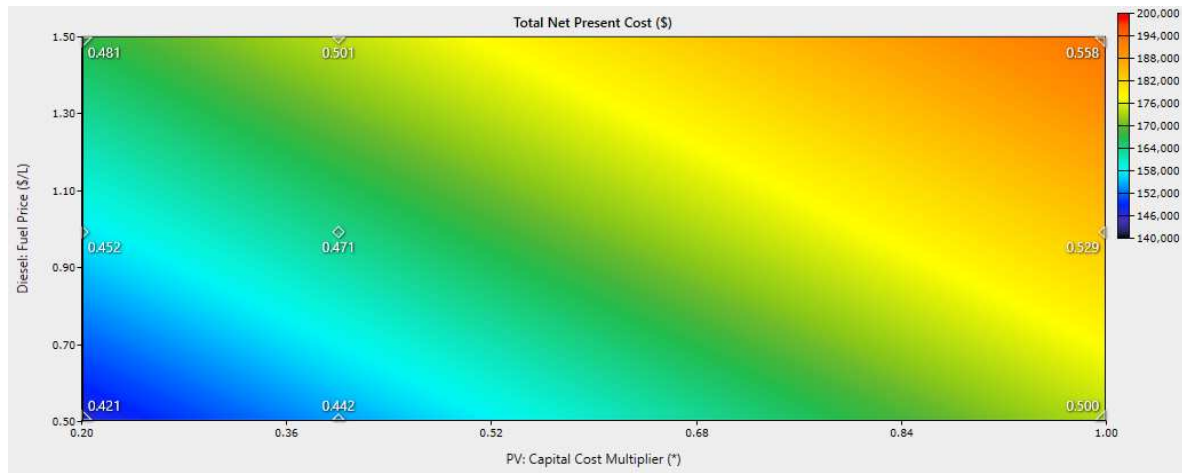


Fig. 14. Impacts of fuel price and PV cost multiplier on COE and NPV of the system.

when the diesel price increases from \$0.5/l to \$1.5/l, the system COE rises from \$0.421/kWh to \$0.481/kWh while the NPC moves from about \$146,000 to \$170,000. This increase in fuel price will adversely hinder the system energy affordability and economic feasibility. As such, diesel systems are not cost-effective in remote localities with diesel price hikes. On the other hand, if diesel fuel can be purchased in bulk in the cities at a moderate price and stored in the village for use, the system will be relatively affordable. With respect to the PV cost multiplier, an increase in this variable from 0.2 to 1.0 results in an increase in the NPC from \$146,000 to \$182,000; while the COE rise from \$0.421/kWh to \$0.500/kWh. All these changes occur at \$0.5/l diesel fuel price. Thus, an increase in the cost of the PV component of the system will make the system unaffordable by the locals except otherwise subsidized by the state or local and international NGOs.

5.0 Conclusion

The aim of this study was to investigate the feasibilities of nine different renewable hybrid systems for remote electrification in Southern Cameroons using the climate data of Wum. The analysis was performed using HOMER Pro version 9.9.2 (64-bits) and the viability characterized mainly on the basis of NPC, COE and the CO₂ emissions of the systems. Among all the studied systems, PV/diesel/small hydro/battery system (scenario G) was found to be the optimum with 67.3 kW of PV array, 10 kW diesel genset connected in a load following dispatch strategy, 13.4 kW of small hydro, 332 units of battery, 53 kW inverter. This gave a COE of 0.443 \$/kWh, compared to 0.674 \$/kWh for scenario E (a pure renewable system). This COE from this system is relatively low compared to 0.691 \$/kWh reported by [30] for a PV/LPG/battery system in the northern part of Cameroon and 0.355 \$/kWh for a micro-hydro/LPG/battery system in the South. The power generation from this system corresponds to 170,095 kWh/yr, of which solar accounts for 57.7%, small hydro 40.5%, and only 1.84% came from the genset. Scenario G is chosen as the best economic system despite its partially pure renewable composition and its relatively high emissions (3.9×10^3 kg of CO₂ per year) mainly based on its low COE, NPC and

related systems costs in table 9. However, from an environmental perspective, scenario E with zero emissions and second lowest COE is the optimum. The CO₂ emissions are attributed only to the diesel component of the systems. The absence of this component decreases the economics of the systems (cost increase) and favours their sustainabilities and environmental friendliness.

The findings from this study equally demonstrate that the optimum systems show very little changes to uncertainties in input variables such as interest rate, flow rate, PV cost, and fuel price. Thus, considering systems supply reliability, ease of implementation, less transmission cost and losses, ease of local maintenance and reduce the cost of long-distance grid extensions to remote localities, off-grid systems are more attractive for rural electrification than grid connections in Southern Cameroons. They are also recommended for environmental friendliness compared to isolated diesel systems. The outcomes of this study are highly instrumental for policy makers and investor as a guide for investment in renewable energy systems in Southern Cameroons and Cameroon as a whole. Further studies using actual measured ground resource data as well as hourly data recommended for the achievement of a more vivid and realistic picture of the viabilities of these systems. Also, we encourage more government dedications through the provisions and the establishment of conducive policies, regulations, incentives and funding mechanisms necessary for the promotion and revitalization the country's renewable energy sector.

References

- [1] V. Khare, S. Nema, P. Baredar, Solar-wind hybrid renewable energy system: A review, *Renew. Sustain. Energy Rev.* 58 (2016). doi:10.1016/j.rser.2015.12.223.
- [2] L. Ayompe, A. Duffy, An assessment of the energy generation potential of Photovoltaic systems in Cameroon using satellite-derived solar radiation datasets, *Sustain. Energy Technol. Assessments.* 7 (2014) 257–264. doi:10.1016/j.seta.2013.10.002.
- [3] A.V. Wirba, A.A. Mas'ud, M.-S. Firdaus, A. Salman, M.T. Razman, A.R. Ruzairi, A.B. Munir, M.E. Karim, Renewable energy potentials in Cameroon : Prospects and challenges, *Renew. Energy.* 76 (2015) 560–565. doi:10.1016/j.renene.2014.11.083.
- [4] CIA, The World Factbook-Central Intelligence Agency, (2017). <https://www.cia.gov/library/publications/the-world-factbook/geos/cm.html> (accessed April 4, 2017).
- [5] E.K. Ackom, D. Alemagi, N.B. Ackom, P.A. Minang, Z. Tchoundjeu, Modern bioenergy from agricultural and forestry residues in Cameroon : Potential , challenges and the way forward, *Energy Policy.* 63 (2013) 101–113. doi:10.1016/j.enpol.2013.09.006.
- [6] Encyclopaedia Britannica, Geographical map of Cameroon, (2012). <https://www.britannica.com/place/Cameroon?oasmId=61957> (accessed April 15, 2017).
- [7] A.K. Sahu, A.M. Shandilya, S.K. Bhardwaj, Rural electrification : Issues and challenges of sustainable development, *Int. J. Emerg. Technol. Adv. Eng.* 4 (2014) 240–246.
- [8] T. Sanchez, T. Tozicka, Rural electrification: The role of the public sector and collective

- action on electricity access for the poor, (2013) 1–20.
<http://cdn1.practicalaction.org/5/1/5149d242-fc2c-4221-a266-690d0ae4f5bb.pdf> (accessed July 15, 2017).
- [9] M.S. Adaramola, S.S. Paul, O.M. Oyewola, Assessment of decentralized hybrid PV solar-diesel power system for applications in Northern part of Nigeria, *Energy Sustain. Dev.* 19 (2014) 72–82. doi:10.1016/j.esd.2013.12.007.
- [10] REN21, Renewables 2016 Global Status Report, Renewables 2016 Glob. Status Rep. (2016) 272. doi:ISBN 978-3-9818107-0-7.
- [11] UNDP, Standardized baseline assessment for rural Off-grid-electrification in sub-Saharan Africa: A standardization tool to streamline and simplify the CDM project cycle, (2013) 56. http://www.climatefocus.com/sites/default/files/Standardized_Baseline_Assessment_for_Rural_Off-Grid_Electrification_in_Sub_Saharan_Africa_Nov2013.pdf (accessed May 10, 2017).
- [12] AEO, Africa Energy Outlook 2014. A focus on energy prospects in sub-Saharan Africa. World Energy Outlook Special Report., (2014).
<https://www.iea.org/publications/freepublications/publication/weo-2014-special-report-africa-energy-outlook.html> (accessed August 12, 2017).
- [13] IEA, Cameroon energy and electricity balances in 2016, IEA. (2018).
[https://www.iea.org/statistics/?country=CAMEROON&year=2016&category=Key indicators&indicator=TPESbyGDP&mode=chart&categoryBrowse=false&dataTable=BALANCES&showDataTable=true](https://www.iea.org/statistics/?country=CAMEROON&year=2016&category=Key%20indicators&indicator=TPESbyGDP&mode=chart&categoryBrowse=false&dataTable=BALANCES&showDataTable=true) (accessed October 29, 2018).
- [14] E. Muh, S. Amara, F. Tabet, Sustainable energy policies in Cameroon: A holistic overview, *Renew. Sustain. Energy Rev.* 82 (2018) 3420–3429.
doi:10.1016/j.rser.2017.10.049.
- [15] USAID, Cameroon Power Africa Fact Sheet, (2016). <https://2012-2017.usaid.gov/powerafrica/cameroon> (accessed October 29, 2018).
- [16] UNDESA, A survey of international activities in rural energy access and electrification, (2014) 104. https://sustainabledevelopment.un.org/content/documents/1272A_Survey_of_International_Activities_in_Energy_Access_and_Electrification.pdf (accessed March 20, 2017).
- [17] R.K. Akikur, R. Saidur, H.W. Ping, K.R. Ullah, Comparative study of stand-alone and hybrid solar energy systems suitable for off-grid rural electrification : A review, *Renew. Sustain. Energy Rev.* 27 (2013) 738–752. doi:10.1016/j.rser.2013.06.043.
- [18] A. Chauhan, R.P. Saini, A review on integrated renewable energy system based power generation for stand-alone applications: Configurations, storage options, sizing methodologies and control, *Renew. Sustain. Energy Rev.* 38 (2014) 99–120.
doi:10.1016/j.rser.2014.05.079.
- [19] M.K. Deshmukh, S.S. Deshmukh, Modeling of hybrid renewable energy systems, *Renew. Sustain. Energy Rev.* 12 (2008) 235–249. doi:10.1016/j.rser.2006.07.011.

- [20] S. Ashok, Optimised model for community-based hybrid energy system, *Renew. Energy*. 32 (2007) 1155–1164. doi:10.1016/j.renene.2006.04.008.
- [21] IEA, Cameroon energy indicators in 2016.pdf, IEA. (2018).
[https://www.iea.org/statistics/?country=CAMEROON&year=2016&category=Key indicators&indicator=TPESbyGDP&mode=chart&categoryBrowse=false&dataTable=INDICATORS&showDataTable=true](https://www.iea.org/statistics/?country=CAMEROON&year=2016&category=Key%20indicators&indicator=TPESbyGDP&mode=chart&categoryBrowse=false&dataTable=INDICATORS&showDataTable=true) (accessed October 29, 2018).
- [22] E.M. Nfah, J.M. Ngundam, Feasibility of pico-hydro and photovoltaic hybrid power systems for remote villages in Cameroon, *Renew. Energy*. 34 (2009) 1445–1450. doi:10.1016/j.renene.2008.10.019.
- [23] T.T. Thomas, K. Alexis, D.B. Salomon, Electricity self-generation costs for industrial companies in Cameroon, *Energies*. 3 (2010) 1353–1368. doi:10.3390/en3071353.
- [24] E. Muh, F. Tabet, S. Amara, The Future of Biogas Production in Cameroon : Prospects , challenges and opportunities, *Curr. Altern. Energy*. 2 (2018) 1–20. doi:10.2174/2405463102666180925141102.
- [25] F.H. Abanda, Renewable energy sources in Cameroon : Potentials , benefits and enabling environment, *Renew. Sustain. Energy Rev.* 16 (2012) 4557–4562. doi:10.1016/j.rser.2012.04.011.
- [26] A.B. Mas’ud, A.V. Wirba, M.-S. Firdaus, N.M.Yunus, I. Mas’ud, A.B. Munir, An assessment of renewable energy readiness in Africa : Case study of Nigeria and Cameroon, *Renew. Sustain. Energy Rev.* 51 (2015) 775–784. doi:10.1016/j.rser.2015.06.045.
- [27] F.H. Abanda, M.B. Manjia, K.E. Enongene, J.H.M. Tah, C. Pettang, A feasibility study of a residential photovoltaic system in Cameroon, *Sustain. Energy Technol. Assessments*. 17 (2016) 38–49. doi:10.1016/j.seta.2016.08.002.
- [28] E.M. Nfah, J.M. Ngundam, Modelling of wind / Diesel / battery hybrid power systems for far North Cameroon, *Energy Convers. Manag.* 49 (2008) 1295–1301. doi:10.1016/j.enconman.2008.01.007.
- [29] E.M. Nfah, J.M. Ngundam, R. Tchinda, Modelling of solar / diesel / battery hybrid power systems for far-north Cameroon, *Renew. Energy*. 32 (2007) 832–844. doi:10.1016/j.renene.2006.03.010.
- [30] E.M. Nfah, J.M. Ngundam, M. Vandenbergh, J. Schmid, Simulation of off-grid generation options for remote villages in Cameroon, *Renew. Energy*. 33 (2008) 1064–1072. doi:10.1016/j.renene.2007.05.045.
- [31] NASA Surface Meteorology and Solar Energy, Surface meteorology and solar energy, (2017). <https://eosweb.larc.nasa.gov/sse/> (accessed April 24, 2017).
- [32] E.M. Nfah, J.M. Ngundam, M. Vandenbergh, J. Schmid, Simulation of off-grid generation options for remote villages in Cameroon, *Renew. Energy*. 33 (2008) 1064–1072. doi:10.1016/j.renene.2007.05.045.
- [33] GlobalPetrolPrice.com, Diesel prices, liter, (2017).

- 759 http://www.globalpetrolprices.com/diesel_prices/#hl59 (accessed April 28, 2017).
- 760 [34] A. Al-Karaghoul, L.L. Kazmerski, Optimization and life-cycle cost of health clinic PV
761 system for a rural area in southern Iraq using HOMER software, *Sol. Energy*. 84 (2010)
762 710–714. doi:10.1016/j.solener.2010.01.024.
- 763 [35] M.S. Adaramola, M. Agelin-Chaab, S.S. Paul, Analysis of hybrid energy systems for
764 application in southern Ghana, *Energy Convers. Manag.* 88 (2014) 284–295.
765 doi:10.1016/j.enconman.2014.08.029.
- 766 [36] A. Ghasemi, A. Asrari, M. Zarif, S. Abdelwahed, Techno-economic analysis of stand-
767 alone hybrid photovoltaic-diesel-battery systems for rural electrification in eastern part of
768 Iran - A step toward sustainable rural development, *Renew. Sustain. Energy Rev.* 28
769 (2013) 456–462. doi:10.1016/j.rser.2013.08.011.
- 770 [37] A.H. Al-Badi, Hybrid (solar and wind) energy system for Al Hallaniyat Island
771 electrification, *Int. J. Sustain. Energy*. 30 (2011) 212.
772 doi:10.1080/1478646X.2010.503276.
- 773 [38] G. Bekele, G. Tadesse, Feasibility study of small Hydro/PV/Wind hybrid system for off-
774 grid rural electrification in Ethiopia, *Appl. Energy*. 97 (2012) 5–15.
775 doi:10.1016/j.apenergy.2011.11.059.
- 776 [39] Canadian Solar, Polycrystalline Canadian Solar module, Can. Sol. Inc. (2014) 2.
777 <http://www.mrsolar.com/canadian-solar-250w-poly-solar-panel/> (accessed June 30, 2017).
- 778 [40] Foshan OUYAD Electronics, Angel-200W-300W-400W-500W small wind turbine, (n.d.).
779 [https://ouyad.en.alibaba.com/product/224262253-](https://ouyad.en.alibaba.com/product/224262253-200285922/200W_300W_400W_500W_Small_Wind_Turbine.html?spm=a2700.8304367.prsea43447.122.739f1526aHFej7)
780 [200285922/200W_300W_400W_500W_Small_Wind_Turbine.html?spm=a2700.8304367](https://ouyad.en.alibaba.com/product/224262253-200285922/200W_300W_400W_500W_Small_Wind_Turbine.html?spm=a2700.8304367.prsea43447.122.739f1526aHFej7)
781 [.prsea43447.122.739f1526aHFej7](https://ouyad.en.alibaba.com/product/224262253-200285922/200W_300W_400W_500W_Small_Wind_Turbine.html?spm=a2700.8304367.prsea43447.122.739f1526aHFej7) (accessed May 20, 2017).
- 782 [41] Kohler Power, Kohler 10kW industrial diesel generator., (2014) 4.
783 <https://power.kohler.com/na-en/generators/industrial/product/10reozdc> (accessed June 30,
784 2017).
- 785 [42] C&D Technologies, TEL-TFA C&D Technologies battery series, (2012) 4.
786 http://cosmos.com.my/wp-content/uploads/2012/12/TEL_TFA-Series.pdf (accessed June
787 30, 2017).
- 788 [43] N. Agarwal, A. Kumar, Varun, Optimization of grid independent hybrid PV-diesel-battery
789 system for power generation in remote villages of Uttar Pradesh, India, *Energy Sustain.*
790 *Dev.* 17 (2013) 210–219. doi:10.1016/j.esd.2013.02.002.
- 791 [44] ENF Solar, Big Power inverter T-IP - 5 kW Power Star W7 Inverter..pdf, (2017).
792 <https://www.enfsolar.com/pv/inverter-datasheet/7317> (accessed July 1, 2017).
- 793 [45] G.J. Dalton, D.A. Lockington, T.E. Baldock, Feasibility analysis of stand-alone renewable
794 energy supply options for a large hotel, *Renew. Energy*. 33 (2008) 1475–1490.
795 doi:10.1016/j.renene.2007.09.014.

Highlights

- PV/diesel/hydro/battery found to be the most viable system with a COE of 0.443\$/kWh.
- Outcome found to be highly relevant to policy makers and investors in Cameroon.
- Hybrid off-grid renewables shows promising prospects for remote applications.
- Limited studies in renewables, less state efforts to boost and revitalize the sector.